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622-233

(NASA-CR-168557) SEASAT DATA UTILIZATION PROJECT Final Report (Jet Propulsion Lab.) 62 p HC A04/MF A01 CSCL 05B

N82-18660

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G3/43 12266

Seasat Data Utilization Project

Final Report

September 30, 198[illegible]

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

622-233

Seasat Data Utilization Project

Final Report

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I. INTRODUCTION

The Seasat-A Project was a proof-of-concept mission whose objectives included demonstration of techniques for global monitoring of oceanographic phenomena and features, provision of oceanographic data for both application and scientific users, and the determination of key features of an operational ocean dynamics monitoring system. The Seasat-A Project Plan was to achieve these objectives over a 1-year flight period.

The Seasat satellite was launched from the Western Test Range, Vandenberg, California, on June 27, 1978 (GMT). After 106 days in orbit a short circuit in the electrical power subsystem resulted in the loss of the satellite. During the three months of orbital operations, the satellite returned a very large volume of data from the world's oceans. Many of these data had never before been available. Dozens of tropical storms, hurricanes and typhoons were observed, and two planned major intensive surface truth experiments were conducted. A careful assessment of mission objective achievability suggested that the primary proof-of-concept objectives of Seasat would be achievable with the data set, both satellite and surface truth, in hand. The Seasat Data Utilization Project was formed with the general object of determining the utility of the Seasat-A microwave sensors as oceanographic tools, as expressed by the goals of the original Seasat-A Project.

The Seasat-A satellite was designed to carry five sensors including a radar altimeter (ALT), a Scatterometer (SASS), a Scanning Multichannel Microwave Radiometer (SMMR), a Synthetic Aperture Radar (SAR), and a Visible and Infrared Radiometer (VIRR). The ALT was a nadir viewing short pulse (3-ns) radar operating at 13.5 GHz. Precision of the altimeter height measurement was expected to be 10 cm RMS for sea states less than 20 m. The estimate of significant wave height was expected to be accurate to ± 0.5 m or 10%, whichever was greater, for sea states less than 20 m. The SASS was an active microwave instrument that illuminated the sea surface with four fan-shaped beams. The amount of energy returned provided an estimate of sea-surface wind magnitude and direction. The transmitted frequency was 14.6 GHz. As a goal, surface winds were to be determined to ± 2 m/s or 10% in magnitude, whichever was greater, and ± 20 deg in direction. The SMMR operated at frequencies of 6.6, 10.7, 18, 21 and 37 GHz with both horizontal and vertical polarizations. Two primary classes of data obtained from SMMR were: sea surface temperature (SST) and surface winds. Liquid water and water vapor were also potentially measurable and were used to formulate path length and attenuation corrections for the altimeter and SASS, respectively. The SST accuracy was expected to be ± 2 K, an important first step in determining SST under cloudy conditions. The accuracy of surface wind measurements was expected to be ± 2 m/s or 10%, whichever was greater. The L-band (1.275 GHz) SAR looked to the starboard side of Seasat with its 100 km swath centered 20 deg of nadir. The goal was to measure oceanic wave lengths and direction of 50 m or greater, sea ice features, iceberg detection, wave-land interfaces and penetration to the surface through major storms such as hurricanes. The VIRR, intended primarily for feature identification, operated with both a visible channel (0.49 to 0.95 μm) providing information on cloud conditions (day only) and a thermal infrared channel (10.5 to 12.5 μm) providing day and night

information on surface and cloud temperatures.

A condition placed on the project was to publish the results of the effort, to the extent possible, in the open literature. This final report will not include detailed project results, but provides a bibliography which provides these details and indicates the success with which the results have been published. Table I-1 summarizes the accuracies obtained by the Seasat-A sensors. In every case the accuracies equal or exceed the goals of the original Seasat Project. Consequently, it can be stated that the primary "proof-of-concept" objectives of the Seasat Project have been achieved.

II. PROJECT PLAN

A. OBJECTIVES

The general objective of the Seasat Data Utilization Project (SDUP) was to determine the extent to which Seasat-A served to demonstrate the utility of microwave sensing from a satellite as an oceanographic tool, as expressed by the performance goals of the original Seasat-A Project.

The utilization of Seasat data had a serial character in that the sensor evaluation activities of the Experiment Teams had to be completed, at least in a preliminary manner, before scientific investigators could utilize the data for problems of interest to them. However, this systematic and thorough assessment, which is completely serial, was unacceptably long as viewed by the data users in the NOAA/NASA-AO and Commercial Demonstration Groups, who have a need from both a programmatic and professional viewpoint to begin data utilization tasks as soon as possible. Because this problem had been recognized for several years by the Experiment Teams and the Project Science Steering Group (SSG), an early preliminary assessment of the geophysical performance of the sensors was required as a part of the SDUP plan.

At the 17th SSG Meeting, October 19, 1978, this situation was focused more sharply by the SSG. In this meeting a Gulf of Alaska Seasat Experiment (GOASEX) Workshop was identified as the basis for limited data release to the NOAA/NASA-AO Group and the Commercial Demonstration Group. The conduct of the GOASEX Workshop, however, did not lessen the urgency of completing delivery of geophysical oceanic data for research and application as soon as possible.

It was recognized that the data set, upon which the preliminary evaluation at the GOASEX workshop was based, was limited in terms of the sample range in wind and sea conditions. Therefore, the application of the data to a broader range of conditions entails some risk. For this reason, the workshop results were reviewed carefully and in some detail in a colloquium to which the SSG, the NOAA/NASA-AO Group, and the Commercial Demonstration Group were invited.

Although the SDUP recognized the three aforementioned groups as end recipients of Seasat data, they did not represent the primary point of delivery for the Project. Specifically, the SDUP delivered processed data to NOAA's Environmental Data and Information Service (EDIS), which, in turn, is responsible for dissemination to the NOAA/NASA-AO Group and to the general

Table I-1. Seasat Results

Sensor	Observable	Demonstrated Accuracy (1σ)	Demonstrated Range of Observable
Altimeter	Altitude	8 cm (precision)	$H_{1/3} \leq 5$ m
	Significant Wave Height ($H_{1/3}$)	10% or 0.5 m	0 to 8 m
	Wind Speed	2 m/s	0 to 10 m/s
Scatterometer	Wind Speed	1.3 m/s	4 to 26 m/s
	Wind Direction	16°	0 to 360°
Scanning Multichannel Microwave Radiometer	Sea-Surface Temperature	1.0°C	10 to 30°C
	Wind Speed	2 m/s	0 to 25 m/s
	Atmospheric Water	10% or 0.2 g/cm^2	0 to 6 g/cm^2
Synthetic Aperture Radar	Wavelength	12%	Wavelength $\geq$ 100 m
	Wave Direction	15°	0 to 360°

public including commercial and scientific communities, both foreign and domestic.

Given the conditions described above, the specific objectives of the Seasat Data Utilization Project were:

(1) To provide, as soon as practical, some limited performance evaluation of the sensors and limited release of the geophysical data to the NOAA EDIS and the Commercial Demonstration Group.

(2) To provide a scientifically credible evaluation of the accuracy and precision of the Seasat sensors in determining sea surface conditions.

(3) To provide a maximum set of geophysical data, commensurate with resources allocated to SDUP, to the NOAA EDIS and the Commercial Demonstration Group.

(4) With the support of the Commercial Demonstration Group, to determine some of the key features of an operational system.

B. WORK PLAN

The Project was organized into five work units to accomplish the required tasks. These work units are described as follows.

1. Project Management

This work unit includes three major tasks:

(1) Overall management of the Project.

(2) Management of resources.

(3) Management of the scientific interface, including coordination and support of the science overview function, and an interface for all non-experiment team data users.

Deliverables. The Project Management and Resources Management report progress and provide deliverables. Deliverables include:

(1) Periodic Project Status Reports

(2) Project Final Report

2. Information Processing

This work unit provided all non-SAR data processing support for the Project and included the following tasks:

(1) Monitoring and expediting the delivery of telemetry data and attitude/orbit data from Goddard Space Flight Center (GSFC) at a

reasonable quality level to all subsequent processing to support the Project objectives.

(2) Completion of the development of the IDPS software to provide a final completion processing of GSFC-provided Project Master Data Files (PMDFs) and Attitude-Orbit files to a Master Sensor Data Record.

(3) Development and maintenance of a catalog system for the Archival Master Sensor Data Record.

(4) Completion of the development and test of the Algorithm Development Facility (ADF).

(5) Operation of the ADF to support geophysical evaluation efforts and limited data deliveries of Interim Geophysical Data Records (IGDRs) to the NOAA EDIS and Commercial Demonstration Group.

(6) Provide IGDRs to Experiment Teams, NOAA EDIS, and Commercial Demonstration.

(7) Provide GDRs to NOAA EDIS.

Deliverables

(1) Archival Master Sensor Data Record.

(2) Interim Geophysical Data Record No. 1.

(3) Interim Geophysical Data Record No. 2.

(4) Interim Geophysical Data Record No. 3.

(5) Interim Geophysical Data Record No. 4 (SMMR).

(6) Computer-Based Data Catalog.

(7) Geophysical Data Records as follows:

(a) A commplete Altimeter GDR in FY80.

(b) Completion of SASS GDRs in FY81.

(c) Completion of the SMMR GDRs in FY81.

3. Evaluation

This work unit consisted of three major tasks:

(1) A Sensor Engineering Assessment Task, which included a validation of sensor processing software through the Sensor Data Record.

(2) A Sensor Geophysical Evaluation Task, which used the total processing system for each sensor and tested the final link of software, the geophysical algorithm. Microwave sensing capability was demonstrated by comparing satellite geophysical measurements with independent surface observations using primarily those measurements made in the GOASEX and Joint Air-Sea Interaction Experiment (JASIN) programs and measurements made in certain ocean storms. The primary mechanism for the evaluation was a series of workshops. The activity in preparation for the workshop and the workshops themselves form the major part of the Sensor Geophysical Evaluation Task. Written reports were made after each workshop. A geophysical algorithm for each sensor was upgraded based on workshop results and was recommended for use in each data release following a workshop.

A principal goal of the Sensor Geophysical Evaluation Task was to publish results in the open literature. To this end, the Workshop Evaluation Reports provided a basis for published papers. Although it was anticipated that many papers will be written, the evaluation task was to ensure that a major paper was submitted for publication for each sensor. Actual publication is at the option of the journal editors.

(3) A Surface Truth Collection Task, which was used primarily in support of the Sensor Geophysical Evaluation Task, but which will also generate an archival surface truth file for the JASIN data set.

Deliverables

(1) Sensor Engineering Assessment Report.

(2) Workshop No. 1 Evaluation Report.

(3) Workshop No. 2 Evaluation Report.

(4) Workshop No. 3 Evaluation Report.

(5) Surface Truth File.

(6) Submittal of papers for publication for each sensor.

4. Synthetic Aperture Radar

This work unit consists of the following tasks:

(1) Providing the sensor geophysical evaluation for the SAR in support of the general sensor evaluation work unit. This

included participation in the workshops, contributing to the Workshop Evaluation Reports, and the submittal of a paper for publication.

(2) Management of the SAR data processing system to provide SAR products to support geophysical evaluation efforts and data deliveries to the NOAA EDIS and Commercial Demonstration Group.

(3) Providing an engineering assessment of the end-to-end SAR system.

Deliverables

(1) Survey processing (optically) of all ocean data. Selected digital processing (26 images).

(2) Contribution to workshop evaluation support (evaluation task milestones).

(3) Submittal of paper for publication.

(4) Engineering Assessment Report.

5. Commercial Demonstration

This work unit consisted of three tasks:

(1) Case Studies Task. This task provided a hindsight assessment of the utility of the Seasat data to the Commercial Demonstration Group, as if it had been provided operationally. These studies also provided a comparison of Seasat data with surface truth obtained by the Commercial Demonstration Group as an evaluation input.

(2) Real-Time System Demonstration. This task provided an operational delivery of satellite data, for an assessment of data utility in an operational environment. Because of the Seasat failure, this task was modified in that Fleet Numerical Oceanography Center (FNOC) data was used.

(3) User Transfer Task. The User Transfer Task included several parts. First, the continuation of the real-time demonstration was considered. The SDUP explored the extension of the effort under other agencies and user sponsorship. It is clear that FNOC will continue to develop the use of remote sensing in pursuit of forecast improvement, and will be interested in data distribution as part of the process.

Second, the Seasat data base will be archived at the NOAA EDIS. The Commercial Demonstration Group will be given a description of this archive and will be assisted in any arrangements they may wish to make with NOAA for access to the data.

In addition, this task will afford an opportunity to continue the relationship which has been developed between NASA and the Commercial Demonstration Group and to enhance the utility of Seasat-type data by using this relationship to provide inputs to future NASA programs.

Deliverables

(1) Interim Case Study Report.

(2) Final Case Study Report.

(3) Real-time Demonstration Evaluation Report.

(4) Letter Report on User Transfer Task

The Real-Time Demonstration Evaluation Report will include a description of the key features of an operational system in accordance with objective (4), listed in Section II-A.

C. SCHEDULE

The schedule at which the Seasat Data Utilization Project tasks were completed is shown in Figure II-1.

III. SENSOR AND GEOPHYSICAL EVALUATIONS

A. INTRODUCTION

The evaluation of the Seasat measurement system has been envisioned as a four-step process. The first three steps, termed engineering assessment, sensor evaluation and geophysical evaluation, respectively, are now complete. The first step was the responsibility of the Seasat Project while the next two were under the auspices of the Seasat Data Utilization Project (SDUP). The fourth step, which is the application of the Seasat geophysical data products to research problems by the scientific community, is currently underway and will continue for some years to come.

In order to perform the engineering assessment, teams were formed from the NASA centers responsible for the development of the sensors to carry out this task. These teams were responsible for assessing the engineering performance of the sensors, and for validating the Project's archival sensor data record. The engineering assessment activity concentrated on the comparison of in-flight data with pre-launch tests data and with design specifications. While engineering assessment for the four low data rate sensors is complete, additional engineering assessment studies are being performed for the SAR.

This section of the report addresses the sensor and geophysical evaluation activities and presents results in summary form. The results of engineering assessment and sensor evaluation were presented in a set of eleven

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SEASAT DATA UTILIZATION PROJECT MILESTONE SCHEDULE

STATUS AS OF 17 AUGUST 1981

	MILESTONES	FY79 J	F	M	A	M	J	J	A	S	FY80 O	N	D	J	F	M	A	M	J	J	A	S	FY81 O	N	D	J	F	M	A	M	J	J	A	S	FY82 O	N	D
1	PROJECT MANAGEMENT WORK UNIT I																																			
2	PROJECT PLAN APPROVED			▼																																
3	PROJECT PLAN REVISION APP'D.																										▼									
4	PROJECT FINAL REPORT																																		▽	
5	STATUS REPORTS			▼						▼				▼				▼				▼														
6	INFO. PROCESSING WORK UNIT II																																			
7	MSDR COMPLETE					▼																														
8	IGDR NO. 1 COMPLETE					▼																														
9	IGDR NO. 2 COMPLETE									▼																										
10	IGDR NO. 3 COMPLETE													▼																						
11	IGDR NO. 4																					▼														
12	ALTIMETER GDR COMPLETE																							▼												
13	SASS 47 DAY GDR																							▼												
14	SASS COMPLETION GDR																											▼								
15	SMMR COMPLETE GDR																																		▼	
16	EVALUATION WORK UNIT III																																			
17	ENGINEERING ASSM'T COMPLETE		▼																																	
18	ENG. ASSM'T PUB (IEEE JOURNAL)																▼																			
19	GOASEX WORKSHOPS	▼				▼																														
20	JASIN WORKSHOP															▼																				
21	STORMS WORKSHOP (NOAA)																						▼													
22	SMMR WORKSHOPS																					▼						▼								
23	GEOPHYSICAL ASSM'T PUBLICATION																																			▽
24	SEASAT COLLOQUIUM										▼																		▼							
25	SYNTHETIC APERTURE RADAR WORK UNIT IV																																			
26	OPTICAL PROCESSING COMPLETE																							▼												
27	DIGITAL 26 IMAGES COMPLETE																							▼												
28	ENG. ASSESSMENT REPORT																																			▽
29																																				
30	COMMERCIAL DEMONSTRATION WORK UNIT V																																			
31	CASE STUDY PLANS					▼																														
32	CASE STUDY INTERIM REPORT													▼										DRAFT				FINAL								
33	CASE STUDY FINAL REPORT																							▼				▼								
34	SDDS SYSTEM OPERATIONAL									▼																										
35	SDDS EVALUATION REPORTS																										▼				▼					
36	USER TRANSFER REPORT																																		▼	
37																																				
38																																				
39																																				
40																																				

NOTES:

Figure II-1. Seasat Data Utilization Project Milestone Schedule

papers which appeared in a special issue of the IEEE Journal of Oceanic Engineering (1980).

The sensor and geophysical evaluation activities, while coordinated by the SDUP, were largely a team effort with participants from NOAA, the U.S. Navy, private industry and several foreign and domestic oceanographic research institutions as well as other NASA centers. The concept of Project-sponsored workshops staffed by multi-discipline teams from numerous organizations as a means of evaluating performance of the entire measurement system from sensors through data processing is a somewhat novel approach. In the case of Seasat, the concept has worked well and has resulted in a relatively extensive performance evaluation in a minimal amount of time. For example, the planning meeting for the Gulf of Alaska Experiment Workshop (GOASEX I) was held in December 1978 at the fall meeting of the American Geophysical Union. Subsequently, the surface and satellite observations were processed, and the workshop was held at JPL during the week of January 22, 1979 with participants from 30 different organizatons. In early February, a review of the findings and conclusions of the workshop was held, and a preliminary draft of the workshop report was distributed. In April, the final GOASEX I Workshop Report was published and the June 29, 1979 issue of Science contained eight articles summarizing workshop results.

B. SURFACE OBSERVATIONS

In order to evaluate the performance of the Seasat sensors in meeting their accuracy goals, in situ observations of the requisite geophysical parameters must be made at the time of spacecraft overflight. The Seasat Project cooperated in two major surface observation experiments which were supplemented with routinely collected data. The first experiment was the independently organized, multinational Joint Air-Sea Interaction Experiment (JASIN), which was conducted in the eastern Atlantic, roughly midway between Scotland and Iceland, in July and August 1978. JASIN produced a set of high-quality surface observation data which have been used in the Seasat evaluation. The second experiment, planned and conducted by NOAA, was the Gulf of Alaska Seasat Experiment (GOASEX). It was dedicated to the early validation of Seasat data. This experiment, which monitored oceanographic and atmospheric parameters during September 1978, was supported by research vessels, weather ships, data buoys, and aircraft. Some 200 overpasses of the JASIN area and about 60 overpasses of the GOASEX area were made. The U.S. Navy's Fleet Numerical Oceanography Center (FNOC) and NOAA's National Climate Center provided global surface reports for the lifetime of the mission.

C. WORKSHOPS

A total of three major workshops, GOASEX I, GOASEX II, and JASIN, as well as numerous mini-workshops, provided the focal point for the evaluation activity. In addition, two major colloquia were held in order to disseminate Seasat evaluation results to the engineering and scientific community. Table III-1 presents a list of workshops and colloquia sponsored by the Project. The corresponding workshop reports are listed in Section VII-B of the bibliography.

Table III-1. Seasat Data Utilization Project Workshops and Colloquia

Name	Date	Location	Special Publication*
GOASEX I	Jan 79	JPL	Science
SMMR I	May 79	JPL	
GOASEX II	June 79	California Institute of Technology	IEEE Journal of Oceanic Engineering
ALT I	June 79	University of Texas	
SMMR II	Sept 79	JPL	
Colloquium	Oct 79	Scripps Institution of Oceanography	
ALT II	Jan 80	Goddard Space Flight Center	Journal of Astronautical Sciences
Seasat-JASIN	Mar 80	JPL	Journal of Geophysical Research
SMMR III	Aug 80	NOAA/NESS	
Storms (NOAA sponsored)	Oct 80	National Hurricane and Experimental Meteorology Laboratory	Report in preparation
SMMR IV	April 80	JPL	
Final Colloquium	May 81	Spring Meeting of AGU, Baltimore, MD	Journal of Geophysical Research

*Section VII-B of the bibliography lists the workshop reports.

The GOASEX workshops were an invaluable first step in an initial evaluation of the performance of the sensors and the data processing system. The surface observations from this experiment have been used extensively to refine the algorithms for extraction of geophysical parameters. In October 1979 a colloquium was held at Scripps Institution of Oceanography where results of the GOASEX workshops were presented.

Surface observations from the JASIN Experiment were treated as a withheld data set; i.e., this data was not made available until the workshop convened so that it could not be used by evaluation team members to tune algorithms. Thus, it provided an objective test to determine if the Seasat program had met its measurement goals.

A general procedure for the workshops has evolved. First, the evaluation teams select a set of satellite data that corresponds to surface observations of interest. Each workshop has evaluated only a small subset (a few hours) of the total Seasat data set. Next, the sensor data is processed to geophysical parameters. Then, the data is presented in a form (e.g., graphical and tabular displays) suitable for comparison with surface observations. In parallel with this activity, the surface observations are processed (edited, normalized, averaged) into a form suitable for comparison and then displayed. The surface observation data is then merged with coincident Seasat data, and various statistical anaylses are made. The evaluation teams then convene, analyze the data, draw conclusions and draft a report.

Considerable effort has been expended by the Project in an ongoing effort to develop the capability to compare satellite and surface oceanic observations. These capabilities include (1) the processing of satellite and surface data to prepare a well-organized data set, (2) the collocation and merging of coincident (time and space) observations, (3) the graphical displays of this data set on various time and space scales in various map projections, and (4) the provision of an extensive set of statistical options. These capabilities, which greatly enhanced the productivity of the evaluation teams, are being transferred to the Ocean Pilot System as part of the SDUP phase-out process. Hence, they will continue to be improved and expanded upon as feedback is obtained from oceanographic researchers.

The status of the sensor and geophysical evaluation activities as of May 1980 are summarized by Born, Lame and Rygh [1981]. The results presented in this reference are updated in the subsequent sections to reflect the current accuracy of the geophysical products.

D. ALTIMETER EVALUATION SUMMARY

Based on the results obtained in the two GOASEX workshops and the two altimeter workshops, it is concluded that the Seasat altimeter has met or exceeded performance specifications over the range of available surface observations ($H_{1/3} \leq 8$ m). The performance of the altimeter as determined during the engineering assessment and workshop activities is summarized in Table III-2. The evolution of the accuracy assessment is described in Table III-3. The bias in the altimeter height measurements, b, and bias in time tag associated with the measurement, Δt, have been determined to be [Tapley, Born

Table III-2. Status of Altimeter Evaluation

Objective	Status	Comments
1. Range (height) precision ±10 cm (1σ, 1 s average)	Objective met up to $H_{1/3} \leq 10$ m	For moderate sea states ($H_{1/3} < 5$ m) precision is 5-8 cm (1σ, 1 s average).
2. Ocean topography solutions on submeter level	Submeter topographic features have been corroborated with surface truth (Gulf Stream and Kuroshio)	Global ocean surface topography variability maps have been produced.
3. $H_{1/3}$ (significant wave height) from 1-20 m, ±10% or 0.5 m, whichever is greater	Objective met within specification up to $H_{1/3} \leq 8$ m	*In situ* data with $H_{1/3} > 8$ m are not available.
4. σ° (backscatter coefficient) ±1 dB	σ° comparison with SASS nadir cells within specifications for $2 \leq \sigma^\circ \leq 16$ dB	Practical range for wind measurements is 2 to 25 m/s.
5. Radial orbit determination to submeter level globally	Present capability is 70 cm (1σ) globally. 50 cm can be reasonable anticipated globally.	Orbit on ALT GDR is accurate to 1.5 m (1σ). Increased precision to 70 cm obtained with improved gravity models using Seasat ALT data.

Table III-3. Evolution of Altimeter Accuracy Evaluation

Workshop/Date	Calibration Results	Comment
GOASEX I/January 1979	· σ_h = 10 cm · $b_h = (-.50 + 11\ \Delta t) \pm 0.11$ m · $\sigma_{H\ 1/3}$ = 0.50 m · Bias in σ° = 1.5 dB	· Significant wave height and σ° analysis performed using GOASEX data. Height calibration performed using Bermuda overflight data.
GOASEX II/June 1979	· Wind speed accuracy = 1.6 m/s ($1 \leq w \leq 10$ m/s) · $\sigma_{H_{1/3}} = 0.3$ m ($0.5 \leq H_{1/3} \leq 5$ m)	· Based on buoy winds. · Based on buoy $H_{1/3}$ measurements. · Data anomalies first examined at this workshop.
Orbit Accuracy Assessment 1/ June 1979	Time tag error . $\Delta t = -79.38 \times 10^{-3}$ s · $b_h = 0.11 \pm 0.07$ m · Radial orbit error $\leq$ 1.5 m (1σ)	· Time tag correction verified from global analysis of crossing arc data. Height bias from further analysis of Bermuda overflight data. Orbit error estimate was based on comparison between independent laser and doppler ephemeris.
Orbit Accuracy Assessment 2/ November 1979	. Radial orbit error $\leq$ 1.5 m · EM bias $\simeq 0.05\ H_{1/3}$ · Ionospheric range correction accuracy = 3 cm (1σ)	· Results based on PGS-S3 special Seasat geopotential. · Electromagnetic sea surface interaction identified as an altitude bias problem. · Ionospheric evaluation accuracy obtained by comparison of global dual frequency doppler and Faraday rotation data.
JASIN/January 1980	· SMMR wet tropospheric correction accuracy = 2.7 cm (1σ). FNOC wet tropospheric correction accuracy = 5.7 cm (1σ)	· Global radiosonde measurements were used to adjust bias in SMMR wet tropospheric algorithm for altimeter and to estimate accuracy of wet tropospheric correction.

and Parke, 1982]: $b_h = -0.11 \pm 0.07$ m, $\Delta t = -79.38 \times 10^{-3}$ s. If the effects of sea state bias are modeled, the height measurement bias becomes $b_h = 0.0 \pm 0.7$ m [Kolenkiewicz and Martin, 1982].

The predominant radial orbit perturbation was found to occur with wavelengths on the order of once/revolution (40,000 km) with an amplitude on the order of 10 km. The RMS of the radial error in the orbit on the altimeter GDRs is approximately 1.5 m. For more recent solutions, the RMS radial error is on the order of 70 cm with a potential for further improvement. Further discussions of the altimeter height and orbit error accuracy assessments are given by Tapley and Born [1980] and Tapley, Born and Parke [1982].

The accuracy of the Seasat altimeter-inferred estimates of significant wave height (SWH) and wind speed has been evaluated by comparison with buoy measurements [Fedor and Brown, 1982, and Webb, 1981]. Comparison of SWH buoy measurements with Seasat data exhibits a mean difference of 0.07 m and a standard deviation of 0.29 m over the range of 0.5 to 5.0 m. A comparison of buoy wind speed measurements with the Seasat altimeter winds yielded a mean difference of -0.25 m/s with a standard deviation of 1.6 m/s over a range of 1 to 10 m/s [Fedor and Brown, 1982].

In addition, an intercomparison of winds determined by the Seasat altimeter, SMMR, SASS and buoys was made [Wentz et al., 1982]. The comparisons show an agreement of 2 m/s for winds less than 10 m/s. The altimeter appears to be biased low at higher wind speeds; however, there are not enough buoy observations for the comparison to be statistically significant.

The applications of the Seasat altimeter data have demonstrated that the data set contains significant oceanographic and geophysical information related to waves, wind speed, sea-surface topography, tides and the marine geoid. Further studies aimed at improving the algorithms to correct for the effects of return pulse shape, SMMR wet tropospheric height correction, sea-surface skewness and shift of the electromagnetic means sea level with increasing sea state are underway.

In addition, an improved knowledge of the satellite orbit is needed to make full use of the altimeter altitude measurement precision. Further effort to improve the force model through combined data analysis solutions (doppler, S-band, laser and altimeter) is underway. These include efforts to improve the models for the geopotential, ocean tides, coordinate system and tracking station location and the spacecraft variable area effects in the drag and solar radiation pressure models.

E. SASS EVALUATION SUMMARY

The assessment of surface wind measurement accuracy has evolved and improved during the evaluation period. This is illustrated in Table III-4, which presents statistics on the comparison of SASS and surface observations after each major workshop. More details can be obtained in Schroeder et al. [1982], Jones et al. [1982], and the various workshop reports (see Bibliography, Section VII-B).

Table III-4. SASS Minus Surface Observation Comparison

Workshop/Date	Windspeed Difference, m/s				Wind Direction Difference[a] Deg		Comments
	Off-Nadir		Nadir				
	Mean	St Dev	Mean	St Dev	Mean	St Dev	
GOASEX/ Jan 79	3.0[b]	2.6	-1.1 to 2.2	4.5	<10	~20	• SASS relative NRCS biases of ≤ 1 dB • Pre-launch model function • No atmospheric attenuation
GOASEX II/ Jun 79	2.0	1.5	None reported		<5	15	• Improved surface truth • Preliminary atmospheric attenuation using SMMR • Preliminary NRCS bias corrections
Seasat-JASIN/ Mar 80	0.8	1.6	Little reported		≤3.4	17.1	• Withheld data set • Highest quality surface observations • Revised CUNY and RSS model function • NRCS bias corrections using Amazon Forest measurements.
Post-JASIN/ May 80	≤0.1	1.4	Good agreement surf. truth & Alt[c]		≤1.7	16.3	• SASS II model function, tuned to JASIN (used in GDR production)

[a]Wind aliases removed by selecting closest direction to surface observation.

[b]At a mean windspeed of 13 m/s, the SASS off-nadir wind speeds were biased 23% higher than *in situ* winds.

[c]See Wentz et al. [1982] and Schroeder et al. [1982] for quantification.

The first comparison of SASS winds with *in situ* winds came during the first GOASEX workshop. These SASS wind data at this time were not corrected for precipitating attenuation and used normalized radar cross section (NRCS) to wind inversion models based on pre-launch aircraft data. The comparisons showed a 23% greater SASS-derived wind speed than *in situ* data, which was determined to be due to small NRCS errors caused by misunderstanding of the direction of maximum antenna gain. Wind direction was, and remains to this date, ambiguous, but techniques are being developed to manually remove aliases. This technique has been successfully demonstrated at the JASIN workshop.

Subsequent to these comparisons, the most significant improvements in the reduction of instrument-related errors have been (1) the evaluation and correction of the relative NRCS biases using Amazon Rain Forest SASS NRCS measurements [Bracalente et al., 1980], (2) the recomputation of the NRCS-wind inversion model function using a more extensive aircraft and SASS measurement data base, and (3) the evaluation and adoption of the algorithm which converts SMMR brightness measurements into useful measurements of attenuation in light to medium precipitation, and corrects the SASS NRCS for attenuation. Preliminary NRCS bias corrections made noticeable improvements in the comparisons at the GOASEX II workshop. However, the comparisons at the JASIN workshop, where all improvements had been incorporated, showed remarkable agreement; it was felt that the significant factor in the improved comparisons between GOASEX II and JASIN had been the improved surface observations of the latter. The post-JASIN comparison uses a wind inversion model based primarily on the JASIN data. This model has been used for GDR production processing.

The post-JASIN comparisons and those of the JASIN workshop are well within the tolerances desired by user groups prior to Seasat launch. The standard deviations of the differences for this case are commensurate with those expected due to communication noise, absolute NRCS biases, differences in sampling areas for SASS versus surface observations, anemometer errors, etc. Thus, SASS was a highly successful demonstration of remote radar anemometry.

SASS wind data has been used to demonstrate the improved identification and location of important meteorological features such as lows, highs, troughs, ridges and fronts. In several instances SASS data have identified low pressure centers which developed into destructive storms 12 to 24 h before they were detected by conventional means. Table III-5 summarizes the status of SASS evaluation.

F. SMMR EVALUATION SUMMARY

The SMMR evaluation effort made steady progress in improving the data processing algorithms. By far, the largest effort in the first year went into developing the antenna pattern correction algorithm, an ambitious attempt to correct more fully than ever before for the antenna sidelobes. A major problem found at the GOASEX workshop was the cross-track bias apparent in the retrievals. By the SMMR I workshop, this problem was traced to the neglect of the cross-polarized signal received by the antenna and was corrected. Another

Table III-5. Status of Microwave Scatterometer (SASS) Evaluation

Objective	Status	Comments
1. Wind speed from 4 $\geq$ 26 m/s; $\pm$2 m/s or 10% (1σ), whichever is greater	Objective met	• Comparisons to JASIN winds, were 1.4 m/s (1σ) for available winds which ranged from 4 to 16 m/s. • For winds above 20 m/s (storms), wind differences were 2.4 m/s (1σ) in non-heavy rain areas.
2. Wind direction: $\pm$20 deg (1σ)	Objective met using external means of ambiguity removal.	• A solution to the ambiguity removal problem is under development.
3. 50-km resolution with 100-km grid spacing, 500-km swath each side of satellite	Objective met	• Processing of all off-nadir data uses SASS fore-aft pairs no greater than 50 km apart.
4. Global, all-weather	SMMR attenuation corrections work well for attenuations up to 6 dB (two way)	• In high wind and rain situations SMMR resolution is too coarse and SASS underestimates winds.

major early problem was the existence of large brightness temperature (T_B) biases. The source of these biases was never firmly established, although calibration errors of a magnitude known to exist can account for the biases. Nevertheless, by the SMMR I workshop, the geophysical algorithms were applying biases to the T_B's which distinctly improved the results.

After these two major problems were corrected, the data were adequate to discover (at the SMMR II workshop) that some passes gave excellent retrievals whereas others gave consistently poor retrievals. This was quickly traced to large systematic temperature changes in the SMMR instrument, coupled with an ad hoc term that had been added to the antenna temperature (T_A) calibration equation. The T_A calibration was then re-examined in detail, and a better equation was developed in time for the SMMR III workshop. Also, at this time, it became apparent that the biases in the T_B's were actually "ramp biases" which vanished at low values of T_B.

Once these problems in the input data to the geophysical algorithm were corrected, it was possible to concentrate on improvements in the geophysical algorithm. The change in sea surface emissivity due to wind was rederived using SMMR data. The most important improvement was made when it was realized that the SST and wind retrievals were being degraded by too much emphasis on the higher frequency channels. New geophysical algorithms which placed more weight on the lower channels turned out to give greatly improved results.

Throughout the evaluation effort, as more data were examined, the conditions that degraded the retrievals were identified. The problem with rain was identified at the GOASEX workshop, sunglint and radio frequency interference (RFI) were noticed in the JASIN workshop, land effects were noted in the SMMR III workshop, and occasional Faraday problems were discovered in the SMMR IV workshop.

The wind and SST retrievals should be discarded where rain or RFI is present, but a correction algorithm can probably improve the sunglint-contaminated data. The bias due to land effects varies with location of the land mass relative to the SMMR swath. Faraday problems add a bias to the outer column and subtract it from the nadir column or vice versa. Consequently, the SST retrievals in these columns should be discarded when this effect is noted. Table III-6 summarizes the evolution of the SMMR geophysical parameter accuracy history.

Because of the open ocean requirement, <u>in situ</u> data necessary to improve and evaluate the SMMR algorithms were obtained painfully slowly. Progress in the SST retrievals depended critically on having accurate, timely XBT observations. The water vapor algorithms were improved by radiosonde observations. Unfortunately, surface observation wind fields in the open ocean were very poor, and evaluation of SMMR wind algorithms had to rely upon SASS wind observations.

The current status of the SMMR geophysical parameter accuracy is summarized in Table III-7. In comparisons with surface observations from several different areas of the world, the Seasat SMMR retrieves SST with negligible bias over the range 10-30°C with a 1σ scatter of one degree or

Table III-6. Evolution of SMMR Evaluation Accuracies

Workshop/Date	SMMR vs. Surface Observation						Comments
	Windspeed, m/s		SST, °C		Atmospheric Water Vapor, g/cm^2		
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	
GOASEX/ Jan 79	1.5	3	3.5	1.5	consistent with 5 mid-latitude radiosondes		. Pre-launch algorithms . Cross track bias problem identified
SMMR I/May 79	1.0	2.5	1.0	2.0	~0.0 ~0.8	0.2 mid-lat. 0.4 tropics	. Solution to cross track bias found
GOASEX II/Jun 79							. SMMR Team elected not to participate pending evaluation of antenna pattern correction algorithms
SMMR II/Sep 79	0.5	2.0	0.5	1.5	~0.0 ~0.8	0.2 mid-lat. 0.4 tropics	. Discovery of instrument calibration problems . Results to this point are primarily of historical interest

Table III-6. Evolution of SMMR Evaluation Accuracies (contd)

Workshop/Date	SMMR vs. Surface Observation						Comments
	Windspeed, m/s		SST, °C		Atmospheric Water Vapor, g/cm^2		
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	
Seasat-JASIN/ Mar 80	~0 to 3.0	2.0	0.6	1.4	~0.0 ~0.6	0.2 mid-lat. 0.4 tropics	• Solution to instrument calibration problems • RFI and sunglint problems addressed • Considered T_B biases • First rain comparisons • Windspeed bias showed geographic dependence
SMMR III/ Aug 80	~0	2.0	~0	1.0	~0	≤10% or 0.2, whichever is greater	• Significant breakthrough in geophysical retrievals • New geophysical • Algorithms introduced • Ramp bias in T_B reported • Effect of land on SST analyzed
SMMR IV/ Apr 81	~0	2.0	~0	1.0	~0	≤10% or 0.2, whichever is greater	• SST monthly means agree with ship means to better than 0.6°C • Faraday problem discovered

Table III-7. Status of SMMR Evaluation

Objective	Status
1. All weather global measurement of sea surface temperature to within 1.5-2°C (1σ) absolute	SST data have zero bias and a scatter of 1.0°C when compared to high quality surface observations from the north Pacific and west Atlantic over the range 10-30°C.
2. Wind speed from 7-50 m/s, ±2 m/s or 10% (1σ), whichever is greater	Comparisons with SASS show biases within 1 m/s and a standard deviation of less than 2 m/s, for wind speeds from 0-25 m/s.
3. Measure integrated atmospheric water	Water vapor determinations in both the tropics and northern latitudes are within the accuracy of the comparison radiosonde data and are unbiased.
4. Measure rainfall rate	The SMMR agrees well with conventional measurements of rainfall, except for cases of light rain with dimensions less than the SMMR footprint.
5. Global, all weather capability	Only very heavy precipitation and cloud cover harm the estimates of liquid water and water vapor. However, moderate rainfall interferes with wind and SST retrieval.

less. There are several limitations that must be accepted in order to achieve subdegree accuracy. The most serious one is that measurements must be restricted to the open ocean--large land masses within 600 km bias the SST retrievals due to the efficiency characteristics of the SMMR antenna. Also, radio frequency interference, sunglint, Faraday rotation in the daytime ionosphere, and heavy rain sometimes degrade the measurements. Fortunately, these restrictions only affect a small percentage of the data set.

Comparisons to the Seasat SASS winds give agreements within 2 m/s. SMMR-integrated water vapor column densities agree with radiosonde measurements to ±10%, which is near the estimated accuracy of the radiosondes themselves. Rainfall rates are in general agreement with surface observations except that light showery precipitation is sometimes missed. No surface observations of column densities of liquid water are made; hence the accuracy of the SMMR estimates is unknown.

G. SAR EVALUATION SUMMARY

The SAR Engineering Performance Evaluation conducted this year has achieved its primary goals. Namely, the radargrammetric capabilities of the instrument have been evaluated and generally met or exceeded the original performance goals. The desired 25-m radar resolution has been amply demonstrated by several digital correlators and ERIM's Precision Optical Correlator. Special purpose processing of imagery by JPL's Precision Digital Correlator and ERIM's Precision Optical Processor has even achieved 6-8 m resolution in the azimuth direction. Position location capabilities have been markedly improved to the point where objects on the earth's surface can be absolutely located to within 200 m, and relative locations determined somewhat more accurately on digitally correlated imagery. Further, the pass-to-pass stability of the radar has been demonstrated to be better than 2 dB. Finally, it has been demonstrated that relative calibration can be performed on the digital imagery with approximately 1-dB accuracy.

The results of the SAR Engineering Performance Evaluation, along with a detailed guide to the proper usage of the SAR imagery and its accompanying ancillary data, are being incorportated into a SAR User's Guide, which should be available sometime in 1982.

The sensor evaluation experiments, which have been conducted thus far, have not had the benefit of such a complete User's Guide; however, much of the information contained in that document was available to the experimenters on a piecemeal basis. Nevertheless, the results of the evaluation experiments are very encouraging.

Both range and azimuth-propagating ocean surface waves have definitely been detected by the Seasat SAR. However, no reliable algorithm has been developed for producing an accurate ocean wave spectrum from the imagery, since the detectability of the waves appears to be a complex function of sea state, wave direction and wavelength, and sensor parameters.

Internal waves travelling in both range and azimuth have been clearly detected by the Seasat SAR, although an experiment in the Strait of Georgia

suggests that detectability improves as the wave propagation vector becomes increasingly range oriented. In the same experiment, a similar directional dependence is indicated for the L-band channel of an airborne SAR system operated by the Environmental Institute of Michigan. However, an accompanying X-band SAR clearly imaged both range and azimuth wave components, and appears to be less sensitive to wave direction.

Although the individual mechanisms are incompletely understood, it is apparent that many more phenomena are detectable with the Seasat SAR. Mesoscale patterns appear as a result of surface wind variations; slicks and streaks of very low radar return may be due to surface organic materials. Current boundaries are sometimes detectable as distinct changes in radar backscatter intensity, and, finally, radar features that are definitely associated with underlying bathymetric features have been detected in the Strait of Dover and over the Nantucket shoals during periods of high tidal current.

Table III-8 presents a summmary of the evaluation results for the SAR.

H. VIRR EVALUATION SUMMARY

The Seasat VIRR was flown to provide day and night images of visible reflectance and thermal infrared emission from ocean, coastal and atomspheric features that could aid in the interpretation of data from other Seasat sensors. The VIRR also provided some quantitative measurements of sea-surface temperature and cloud-top heights. The VIRR scan motor drive failed on August 28, 1978; however, until that time the VIRR functioned as expected. Table III-9 presents the evaluation results for the VIRR. Notice that there are some problems with SST retrievals from the VIRR data; however, this was a secondary objective for the VIRR, and, since imaging quality was unaffected, it was decided not to spend resources on the solution to this problem.

I. CONCLUDING REMARKS

A significant problem for the Seasat Geophysical Evaluation activity was the lack of global high quality *in situ* data over the Seasat performance spectrum to use in the evaluation process. This was largely due to the satellite's brief life. Because of the scarcity of *in situ* data, only a few hours of Seasat geophysical products from a few geographical locations have been examined in depth.

For these reasons, the user should be aware that as he moves out of the geographic locations for which the evaluations were performed or out of the verified performance range, there is a danger of degraded accuracy. However, this situation will improve to some degree as a larger community of users work with the Seasat data, using additional *in situ* data not available to the Project Teams.

In summary, with the exception of the relatively minor caveats indicated in the performance summary tables, all of the Seasat instruments met or exceeded their pre-launch performance specifications.

Table III-8. Status of SAR Evaluation

Objective	Status
1. 25 x 25-m spatial resolution over 100-km swath	Objective met for Digital Processing and ERIM Precision Optical Processing. Resolution for JPL optical processing is 40 m in range and azimuth.
2. Demonstration of capability to measure wavelength and direction	Minimum wavelength detected was 100 m in GOASEX data, 70 m in Gulf Stream squall. Data required on azimuth travelling waves. Internal waves measured in the range of 200 m to 2 km.
3. Provision of data for the study of coastal processes	Data acquired, but sparse surface observations limit interpretability.
4. Ice field/lead charting	Objective met.
5. Iceberg detection	Iceberg has been detected in Beaufort Sea.
6. Fishing vessel surveillance	Objective met for calm surfaces. For disturbed surfaces, ships not seen unless detected by wake.

Table III-9. VIRR Evaluation Status

Objective	Status	Comments
1. Produce visible and infrared images of sufficient quality to enable Seasat investigators to adequately locate significant cloud, coastal, and major ocean thermal features, including at least minimal height differentiation of well-separated cloud tops or strong temperature fronts	Accomplished	Restretching of data in severe tropical storm regions produced excellent examples of detailed cloud structure within these storms
2. Produce sea surface temperatures in clear air areas and cloud top temperatures to within 1°C rms error relative and 1.5°C rms error absolute	For a limited area and data set using a crude atmospheric correction, relative error has been verified to be within the specified limits while absolute error = 1.7°C	Comparisons of northbound with subsequent southbound passes over some clear air areas indicated large SST differences (3 to 4°C) that have not been explained

IV. INFORMATION PROCESSING

The Seasat Data Utilization Project (SDUP) data processing system is depicted in Figure IV-1. Its function was to apply the necessary corrections and conversions to Seasat telemetry data to generate geophysically meaningful data products. The information processing portion of the SDUP consisted of the Instrument Data Processing System (IDPS) and the Algorithm Development Facility (ADF). The IDPS processed all data to create Earth-located, time-ordered master sensor data record (MSDR), sensor data record (SDR), and the master sensor data catalog. The ADF then processed this data into geophysical data record (GDR) sensor files and geophysical files.

A. DELIVERED PRODUCTS

The information processing part of the Seasat Data Utilization Project encompassed the generation of data products for several types of users.

1. Workshop Products

Most workshop products were generated from "team versions" of processors developed for specific areas of investigations. These workshop products were then made available to project science teams for evaluation. After the algorithms and processors were approved by the science teams, they were later placed on the ADF software build and used to produce a final set of geophysical data records.

2. Interim Geophysical Data Records (IGDRs)

These were made available to the public through NOAA's Satellite Data Service Division. They were to be considered by the user not as final products, but were of sufficient accuracy and verified by the sensor algorithm development team to be of use until the final products became available. These IGDR tapes were constrained to contain data over certain zones on the Earth over restricted time periods.

3. Commercial Experimentor Records

Known as ASVT sets of data, these were given to various companies and government elements who entered into an agreement to use geophysically processed Seasat data to investigate an area of interest to their company or government element.

4. Geophysical Data Record (GDR) Geophysical File

These were the final product associated with each sensor. These data products superseded the IGDR products in all cases as being more accurate and covering more of the mission time period. Although they may not be the most accurate possible products, they do represent the final products of the Seasat Data Utilization Project. All GDR tapes were made available to the public through NOAA's Satellite Data Service Division.

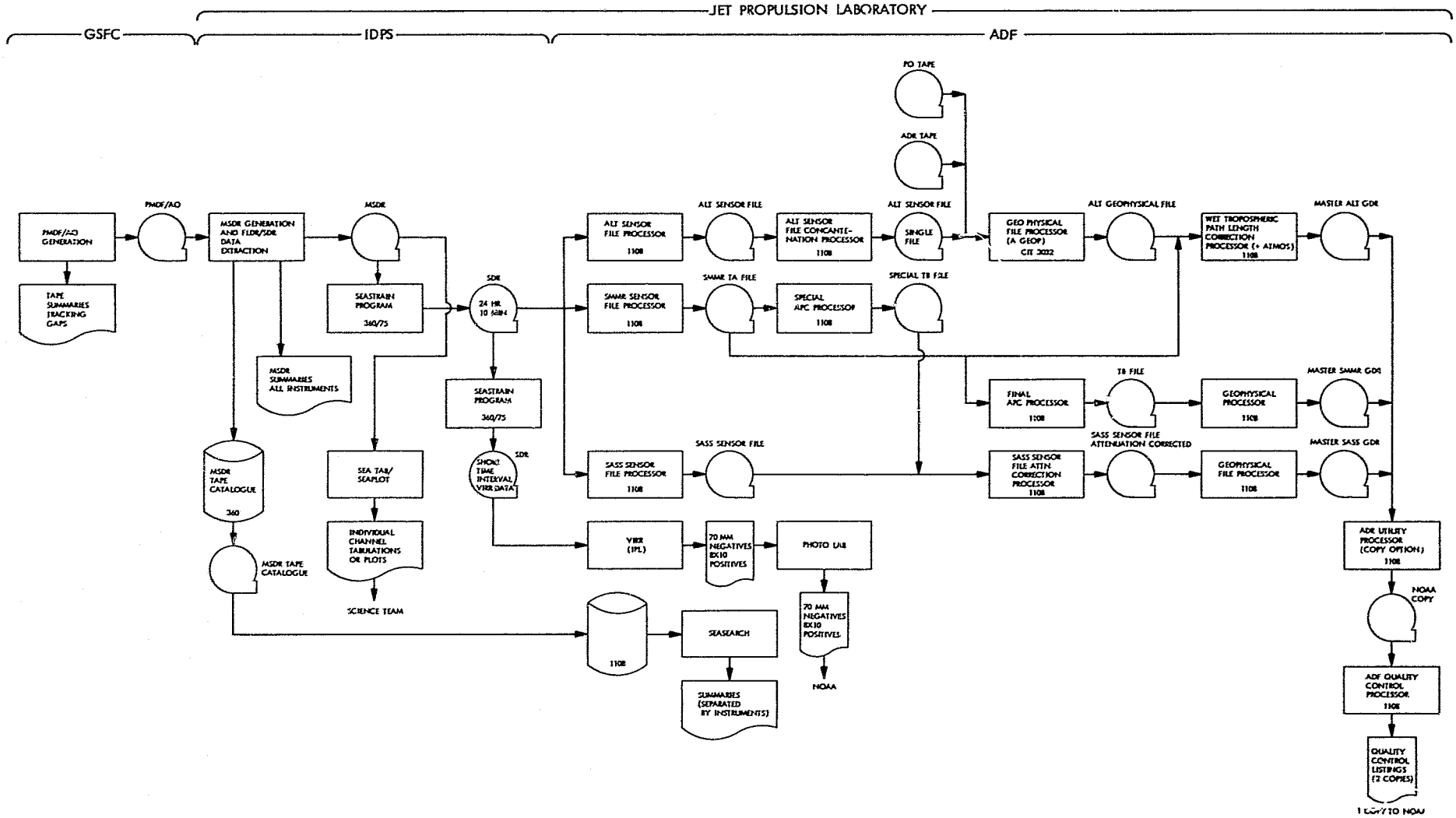

Figure IV-1. SDUP Data Processing System

B. THE GDR PROCESSING

Great attention was paid to checking the final products before release to NOAA. Quality control programs were run using the NOAA copies of the GDR tapes as input. A great many hours of engineering personnel were spent in analyzing the quality control output to ensure that correct and complete processing of the data had been accomplished before releasing the tapes to NOAA for distribution to the general public.

The size of the GDR processors is given in Table IV-1. The size is shown as two parameters, the program code and any accompanying tables necessary for the computation. In most cases the sum of the code and tables did not occupy the main core of the machine during the entire processing run. Rather, overlay of code and buffering of tables reduced the core sizes. It should be noted that all the processors listed ran on the the Univac 1108 and later on the Univac 1100/81 with the single exception of the Altimeter Geophysical File Processor, which ran on the IBM 360-75.

Table IV-2 shows the run times associated with each processor. The times are given as ratios of average computer CPU time per minute of data. In addition, the ratio of the average input-output time per minute of data is also given.

C. GDR TAPE DESCRIPTIONS

Table IV-3 shows the numbers of GDR tapes associated with each sensor. In the sections below some description is given for each sensor GDR set of tapes. Each sensor has a handbook which describes in detail the tape format for that sensor's GDR tapes. In addition, the handbooks contain some information on the contents of the data in the data records on the GDR tapes. More complete descriptions of the algorithms used in processing the data are given in a series of documents for each sensor (see VII-C, Project Reports Section of Bibliography).

1. Scatterometer (SASS) GDR Tapes

The SASS GDR contains 381 tapes. Each tape, in general, contains a quarter of a mission day's worth of GDR data plus a maximum of 10 minutes of overlap data. The Basic Sensor Records, Supplemental Sensor Records, Basic Geophysical Records, and Supplemental Geophysical Records for the quarter day are contained on each tape. Because of the volume of SASS GDR tapes and the fact that many users were not interested in sensor level data, two extractions of the GDR tapes were made. One extraction of 96 tapes contains the Supplemental Geophysical Records (containing the backscatter measurement corrected for attenuation) and the Basic Geophysical Records. Each of these 96 tapes contains data over one mission day. The other extraction set of 48 tapes contains only the Basic Geophysical Records with each tape containing two mission days of data.

The NOAA tapes were sent to NOAA-SDSD, and the master and archive copy tapes were transferred to the Ocean Pilot System at JPL.

Table IV-1. GDR Processors

Processor	Processor size (words) (36-bit words)		
	Code	Data	Total *
ALTPROC	32535	34041	45800
ALT geophysical (IBM 360/75+3032)	78410	40590	119000**
ALGGOPROC	23002	26504	34100
SMMRPROC	29466	31912	40700
SMAPCPROC/SIDLOBN037	28994	46575	54300
SMAPCPROC/SIDLOB	28994	59924	64700
SMAPCPROC/NOSIDLOB	61763	31741	37900
SMGEOPROC (wentz)	27230	38392	47000
SMGEOPROC/CHESTER	24571	37965	45600
SMGEOPROC/SIDLOBN037	24672	37965	45600
SASSPROC	32034	37613	48700
SATTENPROC	28533	29988	50100
SAGEOPROC	28517	47122	57100
VIRRPROC	28541	32942	41200
UTILITY	26694	29198	36000
UTILITY/PLOT	36977	33703	54900
UTILITY/MICROPLOT	38399	34523	57100
UTILITY/SASSFOOT	34319	34335	54400
QUAL	22415	24633	33800
ADFCAT	-	-	-
ASVTWRT	24640	25974	35400
LOCDUMP	21606	26255	36200
SDRDUMP	21887	26303	36200
SMCNVPROC	-	-	-
TAPECAT	18199	13080	22100
SGASEARCH	-	-	-

* Overlaid

** In terms of IBM 32-Bit words

(In each case, about 20,000 words of "CODE" and 10,000 words of "DATA" are "SYSTEM" routines which are common to all processors.)

Table IV-2. ADF Program Times

Processor	CPU Ratio	I/O Ratio
ALT Sensor File	0.11	0.04
ALT Geophysical File	0.04	0.001
ALT Atmos. Correction	0.005	0.00001
SASS Sensor File	0.045	0.004
SASS Attenuation Corr.	0.005	0.0001
SASS Geophysical File	0.095	0.005
SMMR Sensor File (TA)	0.031	0.003
SMMR APC Optimized-No-Sidelobe		
SMMR APC Optimized-Sidelobe	0.059	0.007
SMMR Geophysical File	0.010	0.015
VIRR Sensor File	-	-
SDR Dump	0.0012	0.0002
GDR Utility (Quality control)	0.0047	0.0006
GDR Utility (Concatenation)	0.0012	0.0002
GDR Plot Utility	-	-

CPU Ratio = Minutes of CPU/min of Data
I/O Ratio = Minutes of I/O/min of Data

2. Scanning Multichannel Microwave Radiometer (SMMR) GDR Tapes

The SMMR GDR numbers 381 tapes. Each tape, in general, contains a quarter of a mission day's worth of GDR data plus a maximum of 10 minutes of overlap data. The Basic Sensor Record subtype zero, which contains temperature brightnesses on grids 1, 2 and 3, the Basic Sensor Record subtype one, which contains temperature brightnesses on grid 4, the Supplemental Sensor Record, which contains the antenna temperatures, and the Joint SASS/SMMR Basic Geophysical Record were all written onto these quarter day tapes.

Because a number of investigators have expressed a desire to use the SMMR geophysical data, but could not afford the cost through NOAA to acquire the 381 tape set, an extraction of the Joint SASS/SMMR Basic Geophysical Records has been made. Each of these 24 tapes contains, in general, the data for four mission data days.

The NOAA copies of each set of 381 tapes and 24 tapes were sent to NOAA-SDSD. The masters and archive of each set were transfered to the Ocean Pilot System at JPL.

Table IV-3. GDR and SDR Tapes

Sensor	Data Type	Master	Archive	NOAA
Altimeter	GDR Sensor Level Records	26	26	26
	Geophysical Records	14	14	14
	Sensor Data Records	1006	---	1006
Scatterometer	Sensor & Geophysical Level Records	381	381	381
	Extracted GDR - Geophysical	48	48	48
	Extracted GDR - Geophysical & Geophysical Supplemental	96	96	96
	Sensor Data Records	97	---	---
VIRR	Sensor Data Record	97	---	
SMMR	Sensor and Geophysical Level Records	381	381	381
	Extracted GDR - Geophysical	24	24	24
	Sensor Data Records	99	---	---
	Totals	2269	970	1976

D. OTHER FINAL PRODUCTS FROM THE LOW RATE SENSORS

Several other final data products were produced by the Seasat Data Utilization Project and copies sent to NOAA. These additional data products are described below.

1. Altimeter Sensor Data Records

One of these final products is the set of 1006 Altimeter Sensor Data Record (SDR) tapes. This set of data contains the raw ten per second altimeter telemetry, Earth-located and time tagged. This waveform data is useful to several investigators, particularly those examining anomalies in the data or those trying to isolate geophysical quantities over lakes, rivers or land-locked bodies of water.

2. Visual and Infrared Radiometer Images

Another final product made available is a series of images constructed from the raw Visual and Infrared Radiometer (VIRR) data. These were preserved on 70-mm film negatives. They cover several storms and an area in the northeast Atlantic Ocean where the Joint Air-Sea Interaction (JASIN) Experiment took place.

E. CONCLUSIONS

In processing the final products (GDRs), several lessons were learned. This retrospective knowledge should be of value to later high-volume Earth resource satellite data reduction tasks. Listed below are some of these items.

(1) The great number of tapes used in the Seasat processing resulted in problems with the tape identification system. Several instances arose where tapes were inadvertently overwritten and some data written on the wrong tapes. The overall cure for these problems lies in using a storage media with greater volume capability than magnetic tapes, e.g., optical disks. In the future, large volume storage should be used exclusively for all intermediate storage. Only the final data volumes should be subjected to tape, and even these should be placed on storage media with greater volume and permanence than magnetic tape if it is commonly available.

(2) The essentially serial nature of the processing of the sensor data originated in part from the fact that the sensor teams released the processing algorithms for GDR production for each sensor in a time-phased manner. Consequently, the altimeter processing could begin well before the SASS and the SASS well before the SMMR. This made it possible to use a small team for quality control checking of the projects. If this had not been true, two things would have to have been different to maintain good quality control.

(a) The team checking the final product would have had to have been twice as large as it was and members would have had to have

been assigned to a particular sensor.

(b) The tools for controlling the quality would have to have been expanded, thus doing more of the checking by computer and using less printed output.

(3) Insufficient knowledge of the quality of data was available at the various processing levels. The remedy for this is not immediately apparent without adding greatly to the volume of data to be examined. However, thought should be given to methods of gaining sufficient insight at the various processing steps.

(4) The ability to quality control such a large volume of data properly needs more visibility than was available during the GDR production. Extensive plotting of GDR products would have greatly enhanced the ability to quality control the products properly. These plots, if reduced to microfilm, would also have been an important final product which would have provided needed insight into the data for the investigation using the GDRs.

V. COMMERCIAL DEMONSTRATION

A. INTRODUCTION

The Seasat Commercial Demonstration Program is an outstanding example of a long-term cooperative effort between government and industry in the development and demonstration of the practical and commercial applications of an advanced technology. By the time of its approval as a flight program in 1975, Seasat had a long history of user involvement in the development of the requirements and design goals for the satellite and its sensors. The initial users were drawn from government agencies and academic institutions that were interested in the research and operational applications of the data that could be gathered by an ocean satellite. In 1974 and 1975, NASA sponsored a wide-ranging economic and market study of the potential commercial users, uses and benefits that could be obtained by an operational system that might evolve from the Seasat program. As a part of this study, potential users of the information products that could be produced by this satellite system in the United States and Canada were contacted by the study team. In the process a large number of industrial organizations and several public sector organizations that have a mission to foster private sector activities in areas such as commercial fishing and maritime safety became aware of the NASA program. These commercial users were interested in the fact that the NASA Seasat program and its possible operational derivative could fill a need that had long been perceived by the private sector. This need consisted of two parts:

(1) An improved ocean climatology data base to be used in the design of equipment and the preliminary planning of operations in ocean frontier regions.

(2) Improved ocean condition and weather forecasts for use in improving

the decision processes involved in planning, scheduling and managing commercial activities that take place in and on the oceans.

An important by-product of these economic and marketing studies was that many commercial organizations became active participants in the Seasat users' community that NASA had drawn together under the auspices of the Ocean Dynamics Advisory Subcommittee (ODAS). As a result of this participation and the users' perceived needs, many of these commercial users became interested in the possibility of receiving the Seasat data so that they could perform an independent evaluation on the usefulness of these data to their organizations.

Following a series of meetings between representatives of the commercial users, NASA and program and management personnel, NASA, in 1977, formally approved a commercial demonstration program as a part of its technology transfer effort.

The technology transfer program involving the ocean commmercial user commmunity was originally intended to be based upon the experimental use of Seasat data products by commercial organizations over a two-year period following the launch of Seasat. Each participant was to evaluate the usefulness of Seasat data in the context of their own business operations and to provide NASA with a detailed report. The central feature of the commercial user program was to be a computerized dial-up network, called the Satellite Data Distribution System, to provide the commercial users with near-real-time access to the Seasat-derived measurements as well as analysis and forecast products based upon Seasat and other data sources. Each of the industry participants in the Commercial Demonstration Program was to bear the expense of their own program for the evaluation and use of the Seasat data. Following the premature failure of Seasat in October 1978, the Commercial Demonstration Program was re-evaluated by both NASA and the industrial participants. A joint decision was reached to continue the program in a modified way. The modified program consisted of two components. One component was to be the completion and operation of the real-time data use projects that were to be performed by the commercial participants. In these case studies, it was planned that the participant would evaluate the impacts which that Seasat data might have had on its operations during the life of the satellite and the implications of these impacts on future needs and operations.

B. CASE STUDIES

The premature end of the Seasat mission deprived the commercial users involved in the Seasat Program from evaluating the impact of satellite-derived ocean observations and forecasts, delivered in near-real time, on their various ocean activities. In contrast, and in lieu of real-time processing and distribution of Seasat data, some 18 United States and Canadian commercial users were involved in a series of case studies that utilized Seasat data in various sets of analysis efforts designed to assess the usefulness of these data in marine operations, assuming these data had been delivered to each participating user in near-real time. The commercial users participating in these case study activities are shown in Table V-1.

Table V-1. Case Studies of Participating Commercial Users

Case Study Title	Participating Organizations	Nature of Study
1. Beaufort Sea, Oil, Gas, and Arctic Operations	Esso Resources, Ltd., Gulf Oil of Canada	Comparison of Seasat and other radar data against surface truth. Evaluate ability of satellite data to benefit oil and gas operations in Beaufort Sea
2. Labrador Sea Oil, Gas and Sea Ice	Esso Resources, Ltd., Petro-Canada	Comparison of Seasat wind, wave and ice data against surface truth data, evaluate utility of data for aiding offshore facilities design and production operations in Labrador Sea
3. Gulf of Mexico Pipelines	American Gas Association	Evaluate ability of Seasat data to improve storm prediction capability for determining ocean bottom conditions as they affect subsurface pipelines
4. U.S. East Coast Offshore Oil and Gas	Conoco, Inc.	Comparison of Seasat data against surface truth data from instrumented platforms. Develop data base for improved structural design and production operations
5. Worldwide Offshore Drilling and Production Operations	Getty Oil Co.	Develop data base to aid in operations planning, comparison of Seasat data against surface truth data to determine benefits to offshore drilling and production operations
6. East Pacific Ocean Mining	Deepsea Ventures, Inc., Kennecott Exploration, Inc. and Lockheed Ocean Laboratory	Evaluate ability of Seasat data to improve prediction accuracy of severe storms in tropical Pacific to aid deep sea mining operations
7. Bering Sea Ice Project	Members of Alaska Oil and Gas Assn (conducted by Oceanographic Services, Inc.)	Assess ability of imaging radar data to identify ice characteristics in the Bering Sea to aid in determining ice loads on offshore drilling and production structures

Table V-1. Case Studies of Participating Commercial Users (contd)

Case Study Title	Participating Organizations	Nature of Study
8. North Sea Oil and Gas	Union Oil Co.	Use of Seasat data to develop improved design load data for offshore drilling and production structures
9. Marine Environmental Forecasting in Gulf of Alaska	Oceanroutes, Inc.	Use of Seasat data in generating improved ocean condition forecasts in the Gulf of Alaska to aid offshore oil and gas drilling and production operations
10. Offshore Oil and Gas Operations - Four Ocean Areas	Ocean Data Systems, Inc.	Comparison of Seasat altimeter wave height measurements with conventional climatology for four offshore oil and gas operating areas
11. Optimum Ship Routing	Oceanroutes, Inc.	Use of Seasat data to improve forecasts used in developing optimum ship routing information for various marine transportation operators
12. Tropical and Temperate Tuna Fisheries	National Marine Fisheries Service, Southwest Fisheries Laboratory	Use of ocean condition data from Seasat to aid in the possible improvement of planning and executing of tuna and albacore fishing operations in the Pacific regions
13. Improved Real-Time Weather Forecasting	Atmospheric Environmental Service (Canada)	Use of Seasat data as synoptic observations in the preparation of ocean and weather analyses and forecasts; determine what improvements in forecasts may result

C. SATELLITE DATA DISTRIBUTION SYSTEM

Because of a need to more fully understand and refine the commercial user requirements for a real-time oceanographic processing and distribution system, it was decided, following the failure of the satellite, to complete and operate a data system capable of processing satellite-derived ocean observations, generating ocean analysis and forecast products, and distributing these products to a limited set of commercial users. This system, now known as the Satellite Data Distribution System (SDDS), is based upon the system of products of the U.S. Navy Fleet Numerical Oceanography Center (FNOC) and serves as a pilot demonstration from which the general system requirements are developed for future operational ocean-oriented satellite programs.

The SDDS is designed to provide several levels of data products to the commercial users, with plans to expand these product levels over the lifetime of the system. The current state of SDDS operation distributes data products which represent the state-of-the-art in global oceanic weather products and are of substantial interest and use to commercial ocean operations. While these products currently do not utilize real-time satellite observations of the ocean surface, near-term plans call for the use of real-time observations of sea-surface temperature and marine wind velocities derived from the scanning multichannel microwave radiometer (SMMR) on the NASA NIMBUS-7 satellite.

The SDDS functions in series with the FNOC system to produce user products. Conventional meteorological and oceanographic observations provided to FNOC serve as the input set to the numerical analysis and forecast models. Through the use of large mainframe computers (CDC 6500, Cyber 175, and Cyber 2030), analysis and forecast products are developed on a routine, operational basis (at 6-hour and 12-hour synoptic times). Selected sets of these products are collected by the SDDS and are formatted or tailored to the specific needs and geographical regions of interest of the commercial users. The products that are available to the commercial users include:

(1) Sea-Level and Upper Atmospheric Pressure

(2) Sea-Surface Temperature

(3) Marine Winds

(4) Significant Wave Heights

(5) Primary Wave Direction and Period

(6) Spectral Wave Data

These products are transferred to a NASA-owned PDP 11/60 computer co-located in the FNOC facility for storage and distribution to commercial users.

Commercial users can access the analysis and forecast products in one or more ways. A commercial dial-up packet-switching network provides access to

SDDS. Alpha-numeric products may be obtained on standard teletype terminals at data rates as low as 300 baud. Graphics, as well as alpha-numeric products, are received at a transmission rate of 1200 baud on CRT terminal displays (such as the Tektronix Terminal model 4006:10 and companion hard copy units). Alternatively, a direct computer-computer connection can be established using conventional long-distance telephone circuits with a transmission rate of 4800 baud.

A number of commercial fishing vessels along with several deep ocean mining vessels participating in the Commercial Demonstration Program require ocean forecast products while operating at sea. To provide an on-board capability, daily high-frequency radio-facsimile broadcasts are made from radio station WWD (co-operatively operated by Scripps Institution of Oceanography and the NOAA/National Marine Fisheries Service) in La Jolla, California. Product sets are derived from the SDDS by means of a CRT display terminal and hard copy unit - the resulting hard copy charts being used in a facsimile scanner for subsequent radio broadcast.

D. FISHERIES DEMONSTRATION

Under the Seasat Data Utilization Project, investigations are continuing to more fully understand the utility and benefits of satellite observations of the ocean in, and to, commercial operations. Through such investigations it is possible to assess the usefulness of various satellite-borne sensors in private-sector applications and, with the aid of well-crafted government/private-sector partnerships, efficiently transfer the satellite technology from government-sponsored research to private-sector support and refinement for long-term industrial use and benefit.

An investigation is currently underway to test the applicability of selected satellite observations to U.S. West Coast commercial fishing operations. Ocean color boundaries derived from the NIMBUS-7 are being merged with conventional and other satellite observations to form a set of specially tailored charts depicting key environmental properties which may contribute to more efficient and safe commercial fishing operations. The experimental fisheries charts are made available to commercial fishing vessels by means of daily radio-facsimile broadcasts. Overall, the investigation proceeds in an experimental fashion but within the context of an operational setting, thus providing a valid basis for evaluating the commercial utility of the satellite observations.

Charts which depict key color boundaries as derived from CZCS observations of the ocean surface in cloud-free areas are generated as part of this demonstration. The color boundaries are highlighted through special processing to permit clear depiction on the hand-prepared chart. Color boundaries may identify nutrient-rich regions in which fish may congregate. Additionally, special charts are generated which depict a number of ocean surface temperatures preferred by albacore; coastal surface temperature of importance to coastal trawl fisheries; wind and wave parameters; and areas of wind convergences indicative of both squall activity and possible concentrations of nutrients.

This investigation, which will be conducted over a three-year period, involves a continuing evaluation by participating commercial fishermen. Based on the results of the investigation, the use of the satellite observations and resulting products may continue, fully funded by the participating fishermen, or may be discontinued through lack of experimental success and resulting loss of user interest.

E. CONCLUSIONS

While the Seasat mission ended prematurely, the nearly 100 days of collected data have demonstrated conclusively that wave heights, sea-surface directional wind velocities, ice distribution, and sea-surface temperature and topography can be measured from space. Through the Commercial Demonstration Program it has been shown that this information can be used in marine industries to improve weather or sea-state-related operations; supply better warning of severe wind, rain, or wave conditions; provide a way to improve and manage the resource yield; provide improved navigation through ice and currents; and create a better understanding of the ocean and its dynamics. These more efficient and safe commercial operations can yield annual savings of millions of dollars to marine industries.

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